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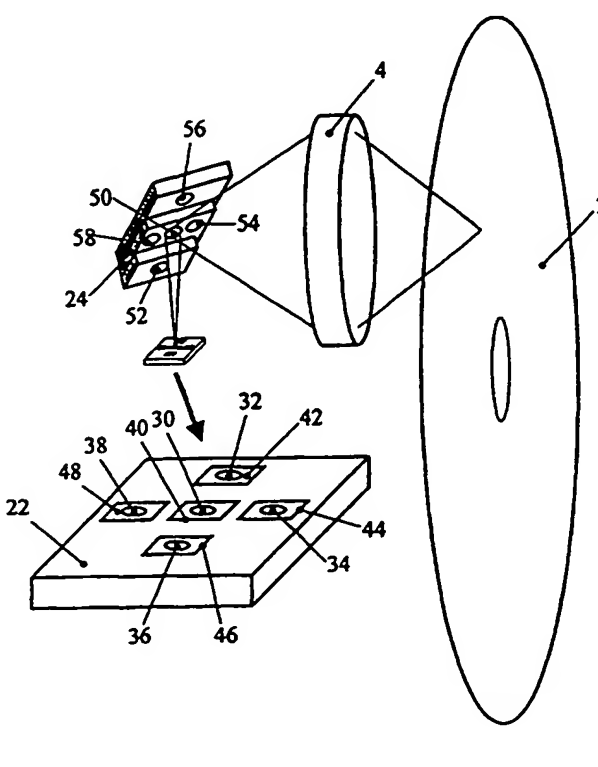
(54) Title: MONOLITHIC VCSEL-BASED OPTICAL PICKUP AND SERVO CONTROL DEVICE



(57) Abstract: A VCSEL-based monolithic optical pickup system with a retaining member (22), a plurality of VCSELs (30, 32, 34, 36, 38) for emitting laser beams, a plurality of detectors (40, 42, 44, 46, 48) for receiving reflected laser beams, and a stepped micro-mirror (24) for reflecting emitted laser beams toward an optical recording media (2) and for reflecting reflected laser beams toward the plurality of detectors. The VCSELs and detectors can be disposed in laser/detector pairs wherein each detector surrounds its respective VCSEL. The system can incorporate upstanding VCSELs each with a sloped and mirrored side surface (154) and with a detector (156) disposed adjacent to the side surface whereby a laser beam emitted by the VCSEL is reflected by an optical recording media onto the side surface of the VCSEL, and then reflected by the VCSEL onto the detector adjacent to the side surface of the VCSEL.

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One will appreciate that there are two possible opportunities to obtain a small, reliable and low-cost optical pick-up that is easily capable of being mass-produced. First, the sizes of the light-emitting and light-detecting units should be reduced and, preferably, these elements should be integrated into a single semiconductor chip. Second, the optical design should be simplified to reduce the number of required elements.

One advantageous solution for decreasing the laser size is to replace an edge-emitting laser currently used in an optical disk pickup with a Vertical Cavity Surface Emitting Laser (VCSEL). The lower size limit for the fabrication of edge-emitting lasers is 50 microns in width and 100-200 microns in length. In comparison, VCSELs can be made to minute circular units of less than 10 microns in diameter. Current VCSELs emit at wavelengths between 650 nm and 980 nm. They are made of GaAs/GaAlAs, InGaAs, GaInP and AlGaAs, InP, having a sandwiched structure of multi-layer reflective surfaces between which multiple quantum-wells are formed. The broad range of available VCSEL wavelengths makes it a good candidate for use in both DVD and CD optical pickups.

Since the date of the VCSEL invention, some designs of optical pickups employing a VCSEL as a light source have been proposed. For example, US Patent No. 5,757,741 to Jiang et al., which is incorporated herein by reference, describes a CD ROM head using VCSELs. In this design as well as in other known prior art devices containing VCSELs, the conventional optical schematic is used. Because of the presence of beam splitters or holographic elements, the light-detecting parts should be distanced from VCSEL. Therefore, the replacement of edge-emitting lasers with VCSELs in these prior art devices has not brought a significant reduction of the size of the optical head and did not simplify its optical design.

It is also known that a group of inventors from the Sony Corporation is developing a promising technique that allows the use of a very simple optical design. Variants of their method have been disclosed by Sahara et al. in US Patent No. 5,568,463, by Doi et al. in US Patent No. 5,883,913, and by Mizuno et al. in the Japan Journal of Applied Physics, 1999, vol. 38, p.2001, all of which being incorporated herein by reference. The main idea of these designs is based on the phenomenon that the diameter of the light beam returning back after reflection from the disk surface is much larger than that of the initial beam emitted by the laser. As a

monitoring of VCSEL power allows it to maintain a desirable level using power feedback control.

In a second embodiment of the invention, three additional VCSELs emitting at a wavelength of approximately 650 nm are added to the chip to provide data reading either from a CD or a DVD.

In a third embodiment of the invention, the integrated chip contains a wedge-like pyramid coated by a metal that serves as micro-mirrors.

In a fourth embodiment of the invention, an edge-emitting laser is inserted into the design of, for example, the third embodiment to provide for a recording of data on a disk surface.

In fifth and sixth embodiments, additional red VCSELs are used in the design of the third embodiment to provide data reading from a CD or a DVD. These two embodiments use different methods for DVD tracking.

With a plurality of embodiments of the present invention for a Monolithic VCSEL-based Optical Pickup and Servo Control Device described, one will appreciate that the foregoing discussion broadly outlines the more important features of the invention merely to enable a better understanding of the detailed description that follows and to instill a better appreciation of the inventors' contribution to the art. Before an embodiment of the invention is explained in detail, it must be made clear that the following details of construction, descriptions of geometry, and illustrations of inventive concepts are mere examples of the many possible manifestations of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

FIG. 1 (prior art) is a schematic representation of a monolithic optical pick-up system using an edge-emitting laser;

FIG. 2A is a schematic perspective view of an optical pickup and servo control system according to the present invention;

FIG. 2B is a diagrammatic view of a monolithic VCSEL/Photodiode chip with monitoring of VCSEL power according to the present invention;

FIG. 2C is a schematic view depicting the role of a stepped mirror under the present invention;

50 by Narui et al. The system contains an integrated single chip 6, lens 4, and optical disk 2. The chip 6 consists of 3 elements, where the central one serves for data reading and tracking purposes, while border ones are needed for detection of focusing error. Each element contains an edge-emitting laser 20. Border elements include a single detector 15, while a central element contains two detectors 14 and 16. The laser beam reflects from the facet 8 that serves as a built-in micro-mirror. As one can see in the insert related to the border element, the returned beam 12 has a much larger diameter on the detector plane than the emitted beam 10. The return beam is spread by diffraction to a spot size with a diameter of 12 μm at the photodiode surface when the numerical aperture is 0.076 and laser wavelength is 0.78 μm. The laser beam diameter in the close zone is in the range of about a few microns.

The laser diode was grown on a (100)-oriented n-type GaAs substrate using reactive ion etching. Nondoped GaAs and p-type GaAs layers were selectively grown forming a crystal (111) B facet as a built-in micro-mirror 8. The angle between (100) and (111) faces is 55 degrees, so the laser beam is emitted at angle 18 to substrate equal to 70 degrees. The focus error signal is obtained by comparing the spot size at the photodiodes 15 and 17. The tracking error signal is obtained by the difference in the photo response of the separate diodes 14 and 16 at the center of the chip using a push-pull method.

Figures 4A and 4B are schematic representations of another monolithic design of Sony's optical pickup disclosed by Mizuno et al. in Japan Journal of Applied Physics, 1999, vol. 38, p. 2002. The light beam emitted from the strip laser diode 20 is reflected by the built-in mirror, which is one of the three reflective surfaces of pyramid 94, and is focused through the objective lens on the disc. The return beam 98 is spread by diffraction on the complete pyramid 94, and its half is deflected back to the laser side, while another half is split by the other two reflective surfaces of the pyramid into 2 fractions. After reflection, these fractions are irradiated on the two quadrant photodiodes 92 on the GaAs substrate. It was reported that covering such structure by glass with a small window improves the sensitivity of the system to tracking and focusing errors. Tracking error is determined with a push-pull method, and focusing error is measured with a knife-edge or Foucault method. The

Beam Epitaxy (MBE) or Metal Organic Chemical Vapor Deposition (MOCVD) processes along with lithography.

In a VCSEL area, the following layers form sequentially: the bottom Distributed Bragg Reflector (DBR) 78, the multiple quantum well active region 68, and the top DBR 28. The optical aperture 64 of the VCSEL is made with either oxidation or ion implantation processes. All named layers together form a VCSEL. The diameter of the aperture 64 can be made as small as 3 microns.

Photo diode 26 is formed on the top of the VCSEL. The Metal-Semiconductor-Metal (MSM) detector is preferred. In this case, the top VCSEL electrode will serve as a bottom electrode for the detector. The positive voltage will be supplied on a bottom metal layer of the MSM. The negative voltage will be supplied to the top of the MSM diode and to the substrate of the VCSEL. After the photo diode 26 is constructed, the central hole is etched in it up to the VCSEL structure. The diameter of the hole should be close to the VCSEL clear aperture. An additional photo diode 88 is placed below each integrated VCSEL/Detector structure for monitoring the power of the VCSEL.

Figure 2C depicts the role of a stepped mirror 24 in the optical schematic according to the present invention. It is seen that the beams from lasers 32, 30, 36 after reflection from different steps of a mirror 24 have origins 39, 31, 35 correspondingly, which are differently distanced from the lens 4. The beams from the perpendicular line of VCSELs 34 and 38 are reflected from the same step of the mirror 24 as the central beam. Therefore, they do not experience optical paths differences. Lasers 34 and 38 are used for tracking error detection with a 3-beam method. To practice this method, focal spots from lasers 34 and 38 on the disk should be slightly shifted in opposite directions away from the track assigned to the central VCSEL 30. Under this arrangement, the differential signal from detectors 44 and 48, which are associated with lasers 34 and 38, serves as a TES.

Figure 2D demonstrates the principle of detecting focus error signal under our design. After reflection from stepped mirror 24, the effective light sources 39, 31, 35 for the beams from lasers 32, 30, 36 are shifted along the optical axis as related to each other. As a result, these beams 39, 31, 35 are focused by lens 4 at the different distances from the disk 2. With this, returned beams are focused at different distances from the detector planes. Therefore, the spot sizes from these

structure forms a prism with reflective faces (111) and (-1,-1,1) and cleavage planes described as (-1,1,0). Detectors 156 are grown on the same substrate 158 as a VCSEL. The reflective planes are tilted to horizontal planes at 55 degrees. Therefore, the returned light is deflected by approximately 70 degrees and is directed to detectors 156. Because the size of a top side of a prism is close to the VCSEL aperture, which is about 3 microns, while the diameter of returned beam is more than 10 microns, only the small part of returned light is not detected.

Returning again to Figure 5A, the top view of all elements is shown. The border elements serve for the tracking purpose, and the tracking error signal (TES) is determined as:

TES = (D116+D102) – (D110+D108)

The signals from the diodes surrounding the central VCSEL are used to construct a Data Signal (DS):

DS = (D112+D114)+D106+D104).

The focus error signal (FES) is made using the Foucault method because each half aperture of the returned beam is detected by separated photo diodes:

FES = (D114-D112) + (D104-D106).

The glass with a transparent small window 120 covers the chip to improve the signal-to- noise ratio during detection of error signals.

Figure 6 is a diagrammatic view of still another embodiment of the invention that provides the opportunity of recording data on the disk surface. For this purpose, a powerful edge-emitting laser 122 is inserted into the chip design. The light from this laser is reflected by the face of prism 100 and is focused by lens 4 on the disk 2 during the recording procedure. The reflected light, with the help of diodes 114 and 112, is used for the focusing correction. The border VCSELs along with accompanying diodes 116, 102, 110, 108 are used for the tracking correction. When reading data, the central VCSEL on the chip is activated instead of edge-emitting laser 122.

Figure 7A depicts a diagram of an integrated chip designed for reading both CDs and DVDs. One can see two lines of VCSELs 100 and 140 wherein the direction of each line is approximately along the tracks on the disk. These triads are switched when the registered medium is changed from CD to DVD and back. The line on the right side of the figure contains VCSELs with a wavelength of 650 nm,

elements as a means for performing a specific function, at times without the recital of structure or material. 7As the law demands, these claims shall be construed to cover not only the corresponding structure and material expressly described in this specification but also equivalents thereof that may now exist or be developed hereafter.

a fourth means for generating an optical beam disposed on the retaining member that is oriented to emit beams directed at the first mirror surface;

a third mirror surface that is stepped relative to the first and second mirror surfaces; and

a fifth means for generating an optical beam disposed on the retaining member that is oriented to emit laser beams directed at the third mirror surface;

whereby laser beams emitted by the fourth and fifth means for generating an optical beam follow optical paths that are different in length than one another and whereby beams emitted by the first, second, and third means for generating an optical beam follow optical paths that are different in length than the lengths of the optical paths followed by beams emitted by the fourth and fifth means for generating an optical beam;

whereby spot sizes of beams reflected onto the means for detecting a reflected data stream paired with the first, second, third, fourth, and fifth means for generating an optical beam can be used to provide a focus error signal and thereby can be employed for focus error detection relative to the optical recording media.

5. The Monolithic Optical Pickup and Servo Control Device of claim 1 **characterized in that** the system further comprises a means for recording data on an optical medium.

6. The Monolithic Optical Pickup and Servo Control Device of claim 5 **characterized in that** the means for recording data comprises an edge-emitting laser.

7. The Monolithic Optical Pickup and Servo Control Device of claim 1 **characterized in that** the plurality of means for generating an optical beam comprises a plurality of VCSELs.

8. The Monolithic Optical Pickup and Servo Control Device of claim 1 **characterized in that** the plurality of means for generating an optical beam comprises a first plurality of means for generating an optical beam that generate optical beams of a first wavelength for interacting with a DVD and a second plurality

each detector to detect more reflected light than can be reflected onto the VCSEL of that laser/detector pair.

14. The VCSEL-based monolithic optical pickup system of -claim 9 **characterized in that** the system further comprises a means for focusing the laser beams emitted by the plurality of VCSELs onto the optical recording media.

15. The VCSEL-based monolithic optical pickup system of claim 9 **characterized in that** the means for reflecting laser beams emitted by the plurality of VCSELs toward optical recording media and the means for reflecting laser beams reflected from the optical recording media toward the plurality of detectors comprises at least a first mirror surface and a second mirror surface wherein the first mirror surface is stepped relative to the second mirror surface.

16. The VCSEL-based monolithic optical pickup system of claim 15 **characterized in that** the plurality of VCSELs and the first and second mirrored surfaces are disposed with at least one VCSEL oriented to emit a laser beam directed at the first mirrored surface and at least one VCSEL oriented to emit a laser beam directed at the second mirrored surface.

17. The VCSEL-based monolithic optical pickup system of claim 16 **characterized in that** first, second, and third VCSELs are oriented to emit laser beams directed at the second mirror surface whereby laser beams emitted by the first, second, and third VCSELs follow optical paths that are substantially equal in length and whereby two of the first, second, and third VCSELs can provide a tracking error signal and thereby can be employed for tracking error detection relative to the optical recording media.

18. The VCSEL-based monolithic optical pickup system of claim 17 **characterized in that** the system further comprises:

a fourth VCSEL disposed on the substrate that is oriented to emit laser beams directed at the first mirror surface;

a detector aligned on the retaining member to receive laser beams that have been emitted by the seventh VCSEL and reflected back from the optical recording media;

an eighth VCSEL disposed on the retaining member that is oriented to emit laser beams directed at the third mirror surface;

a detector aligned on the retaining member to receive laser beams that have been emitted by the eighth VCSEL and reflected back from optical recording media;

whereby the VCSEL-based monolithic optical pickup system can be used as a CD/DVD optical head wherein the detectors aligned to receive laser beams emitted by the seventh and eighth VCSELs can be used for focusing correction and wherein the two detectors aligned to receive laser beans emitted by the sixth VCSEL can be used for tracking error detection under a push-pull method.

23. A VCSEL-based monolithic optical pickup system for use with optical recording media, **characterized in that** the optical pickup system comprises:

a retaining member with a first surface and a second surface;

an upstanding first VCSEL that projects from the first surface of the retaining member for emitting laser beams;

wherein the first VCSEL has a first side surface disposed opposite to a second side surface, wherein at least a portion of at least the first side surface is mirrored, and wherein at least the first side surface is disposed with an exterior angle between the first side surface of the first VCSEL and the first surface of the retaining member that is obtuse;

a detector disposed on the first surface of the retaining member adjacent to the first side surface of the first VCSEL;

whereby a laser beam emitted by the first VCSEL can be directed to an optical recording media, then reflected from the optical recording media onto the first side surface of the first VCSEL, and then reflected by the first side surface of the first VCSEL onto the detector adjacent to the first side surface of the first VCSEL.

24. The VCSEL-based monolithic optical pickup system of claim 23 **characterized in that** the first side surface of the first VCSEL is disposed with an

and wherein a first detector and a second detector are disposed on the first surface of the retaining member adjacent to the second side surface of the second VCSEL whereby a data signal can be generated by adding the combined signals from the first and second detectors disposed adjacent to the first side surface of the second VCSEL to the combined signals from the first and second detectors disposed adjacent to the second side surface of the second VCSEL and whereby a focus error signal can be generated by adding the difference between the signals from the first and second detectors disposed adjacent to the first side surface of the second VCSEL to the difference between the signals from the first and second detectors disposed adjacent to the second side surface of the second VCSEL.

28. The VCSEL-based monolithic optical pickup system of claim 26 **characterized in that** the system further comprises fourth, fifth, and sixth VCSELs disposed on the retaining member each of the fourth, fifth, and sixth VCSELs with a first side surface disposed opposite to a second side surface, wherein the first and second side surfaces are mirrored, and wherein the first and second side surfaces are disposed with an exterior angle between each side surface and the first surface of the retaining member that is obtuse.

29. The VCSEL-based monolithic optical pickup system of claim 28 **characterized in that** the first, second, and third VCSELs are disposed in a first alignment, wherein the fourth, fifth, and sixth VCSELs are disposed in a second alignment, and wherein each of the first and second alignments are disposed to align with tracks on an optical recording medium.

30. The VCSEL-based monolithic optical pickup system of claim 29 **characterized in that** the first, second, and third VCSELs of the first alignment emit laser beams at a first wavelength and wherein the fourth, fifth, and sixth VCSELs of the second alignment emit laser beams of a second wavelength that is different from the first.

31. The VCSEL-based monolithic optical pickup system of claim 30 **characterized in that** the first wavelength is approximately 650 nm whereby the first,

36. The VCSEL-based monolithic optical pickup system of claim 35 **characterized in that** the first wavelength is approximately 780 nm whereby the first, second, and third VCSELs can be used for CD reading and wherein the second wavelength is approximately 650 nm whereby the fourth VCSEL can be used for DVD reading.

37. The VCSEL-based monolithic optical pickup system of claim 34 **characterized in that** two detectors are disposed outboard of the first VCSEL, four detectors are disposed between the first and fourth VCSELs, and four detectors are disposed outboard of the fourth VCSEL whereby a phase difference method of tracking error detection can be employed.

38. The VCSEL-based monolithic optical pickup system of claim 23 **characterized in that** the system further comprises a means for focusing the laser beam emitted by the first VCSEL onto the optical recording media.

39. The VCSEL-based monolithic optical pickup system of claim 23 **characterized in that** the system further comprises an edge-emitting laser disposed on the retaining member wherein the edge-emitting laser is aligned to emit a laser beam directed at the first side surface of the first VCSEL whereby the laser beam emitted by the edge-emitting laser will be reflected by the first side surface toward the optical recording media whereby the VCSEL-based monolithic optical pickup system can record data on the optical recording media.

40. A monolithic optical pickup system for use with optical recording media, **characterized in that** the optical pickup system comprises:

a retaining member with a first surface and a second surface;

an upstanding first means for generating an optical beam that projects from the first surface of the retaining member for emitting optical beams;

wherein the first means for generating an optical beam has a first side surface disposed opposite to a second side surface, wherein at least a portion of at least the first side surface is mirrored, and wherein at least the first side surface is disposed with

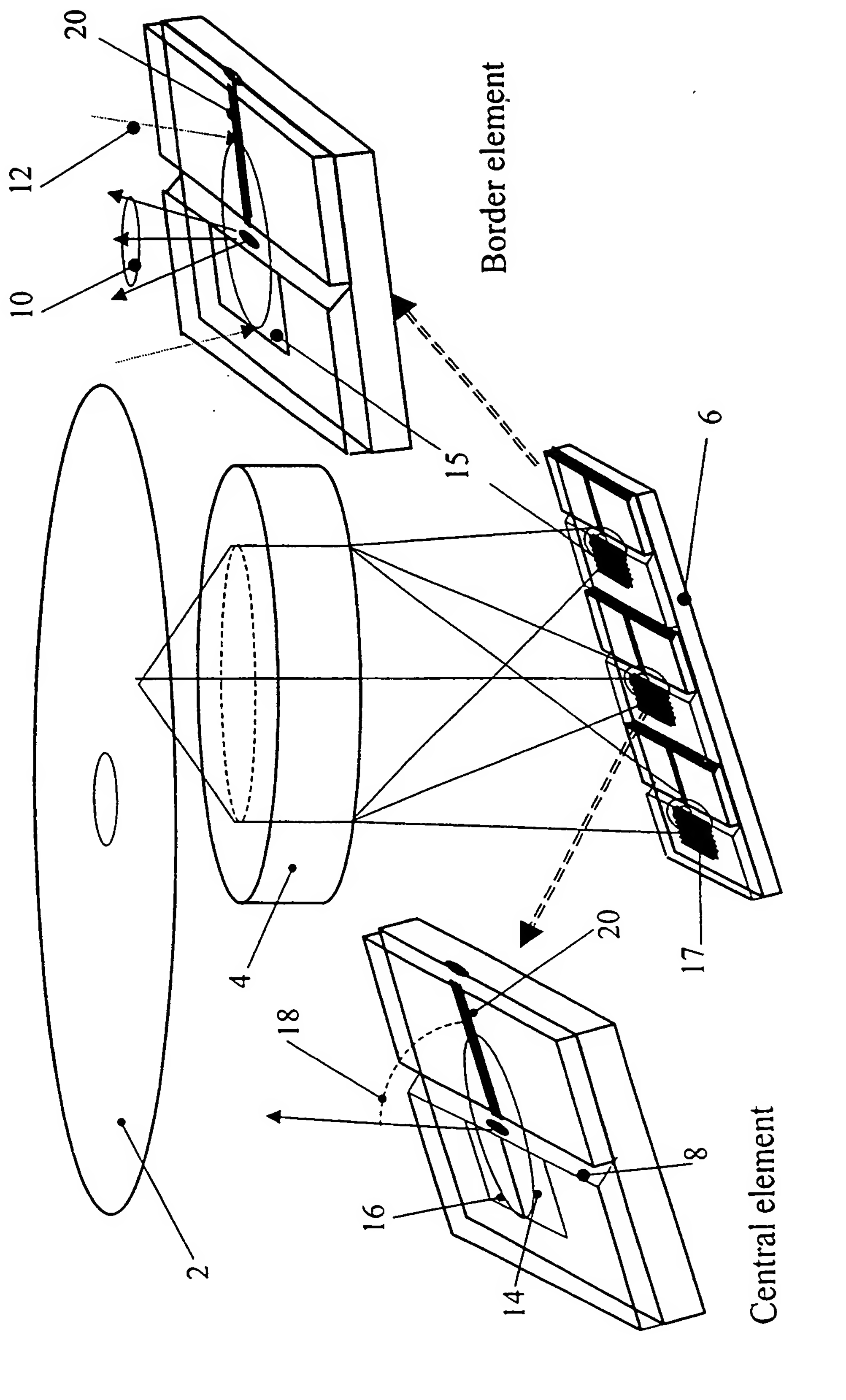

Figure 1 (Prior Art)

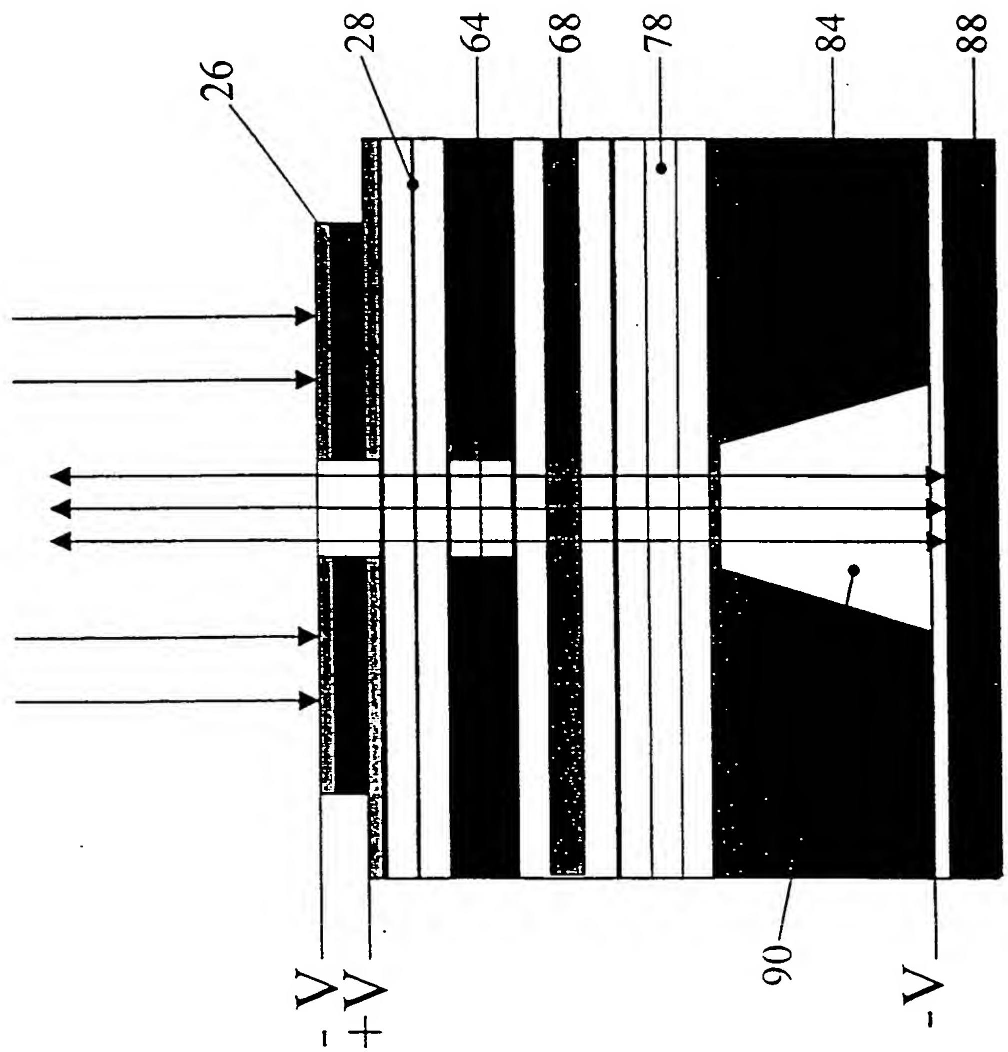

Figure 2B

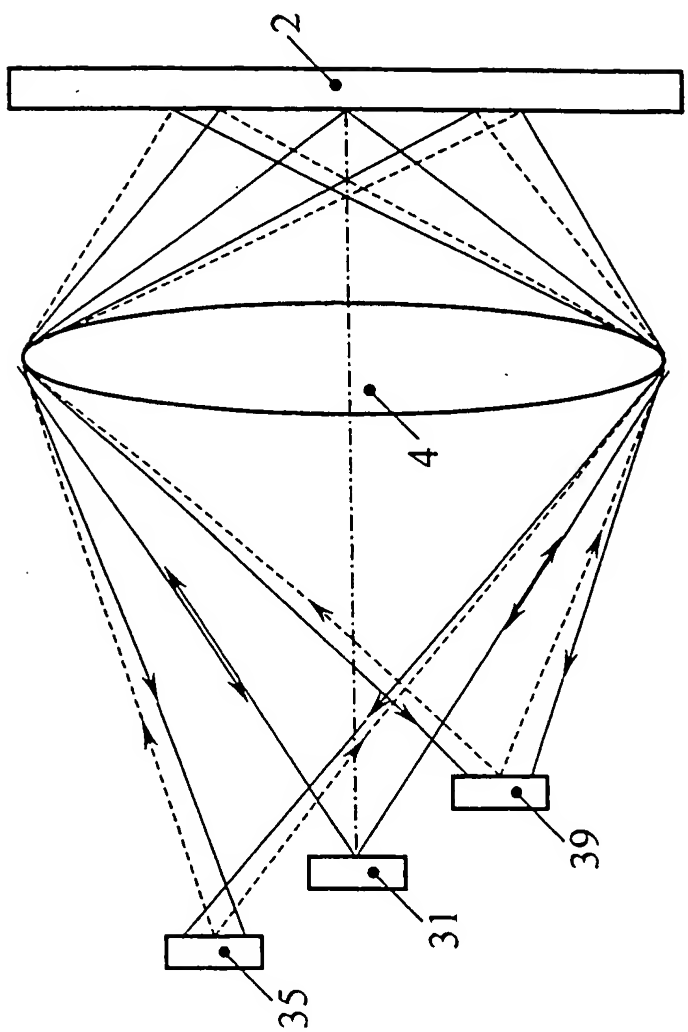

Figure 2D

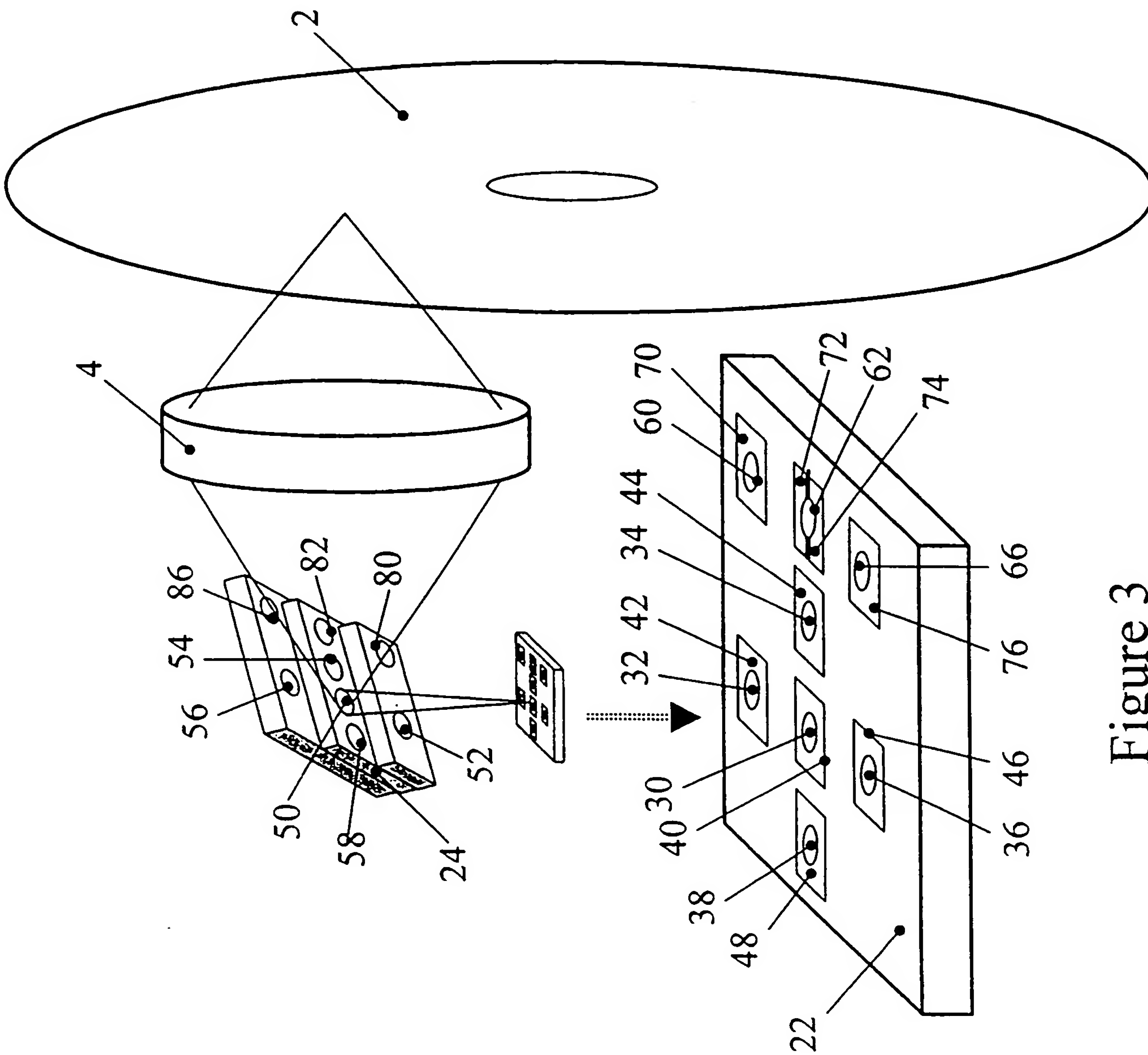
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Figure 3

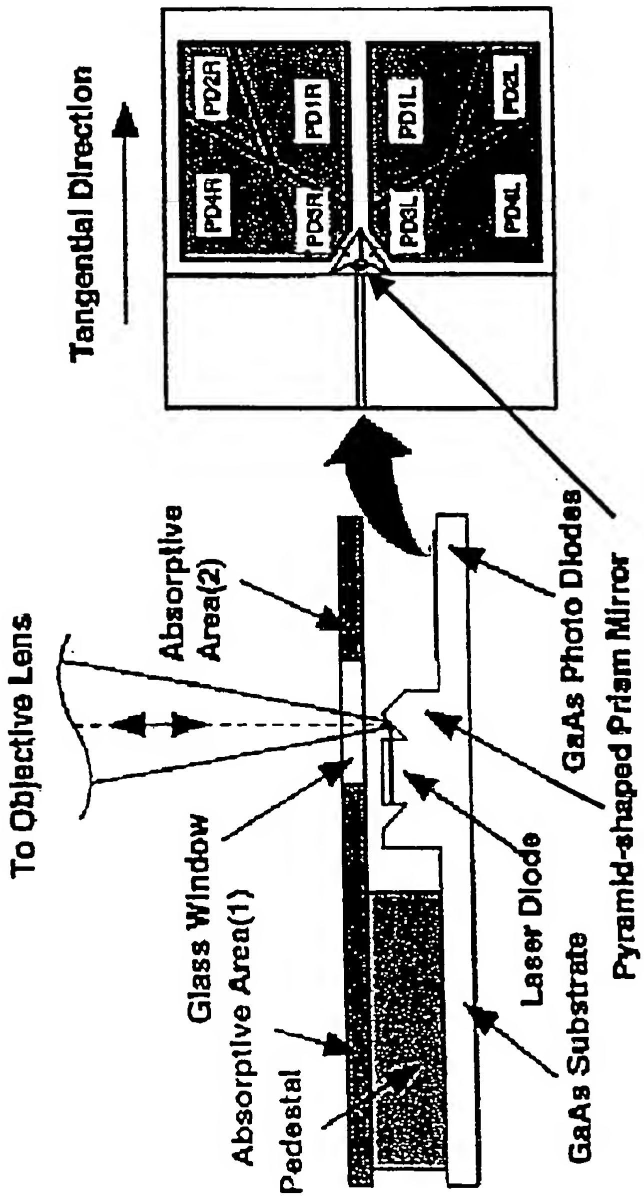

Figure 4B (Prior Art)

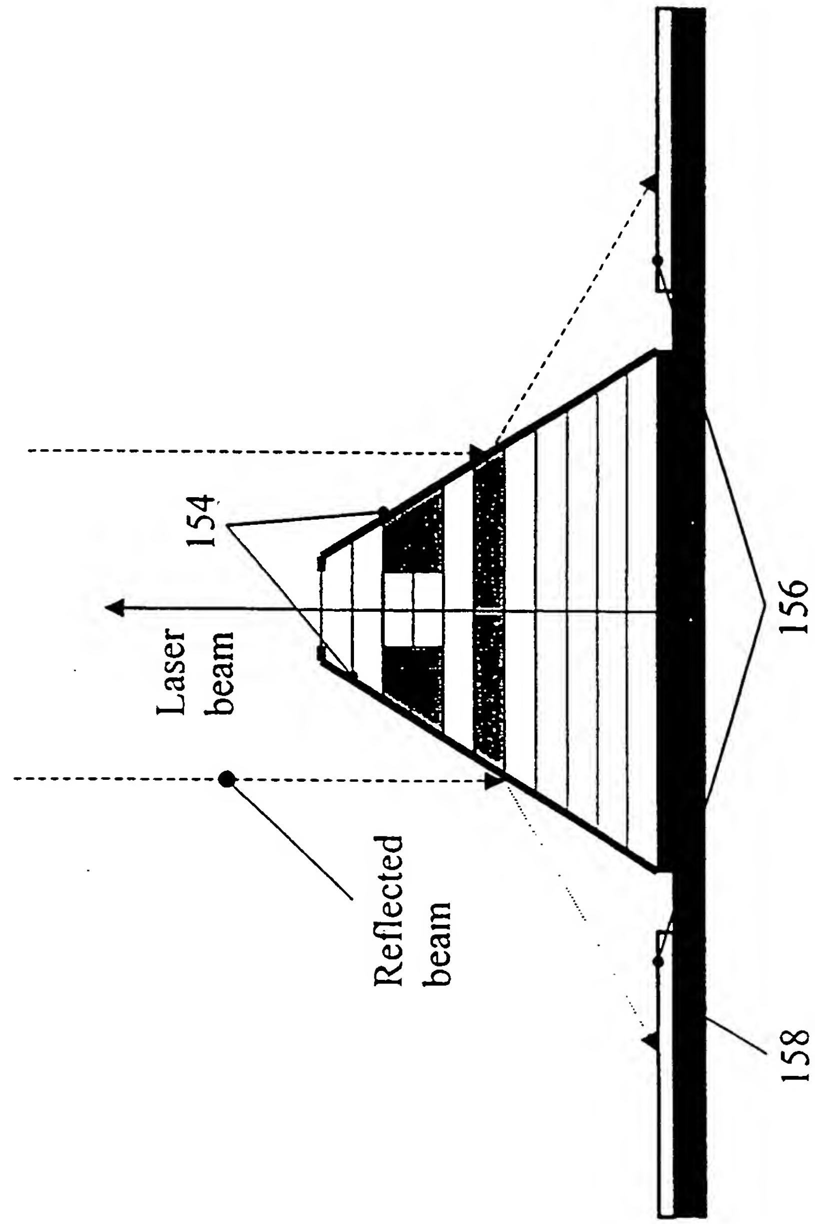

Figure 5B

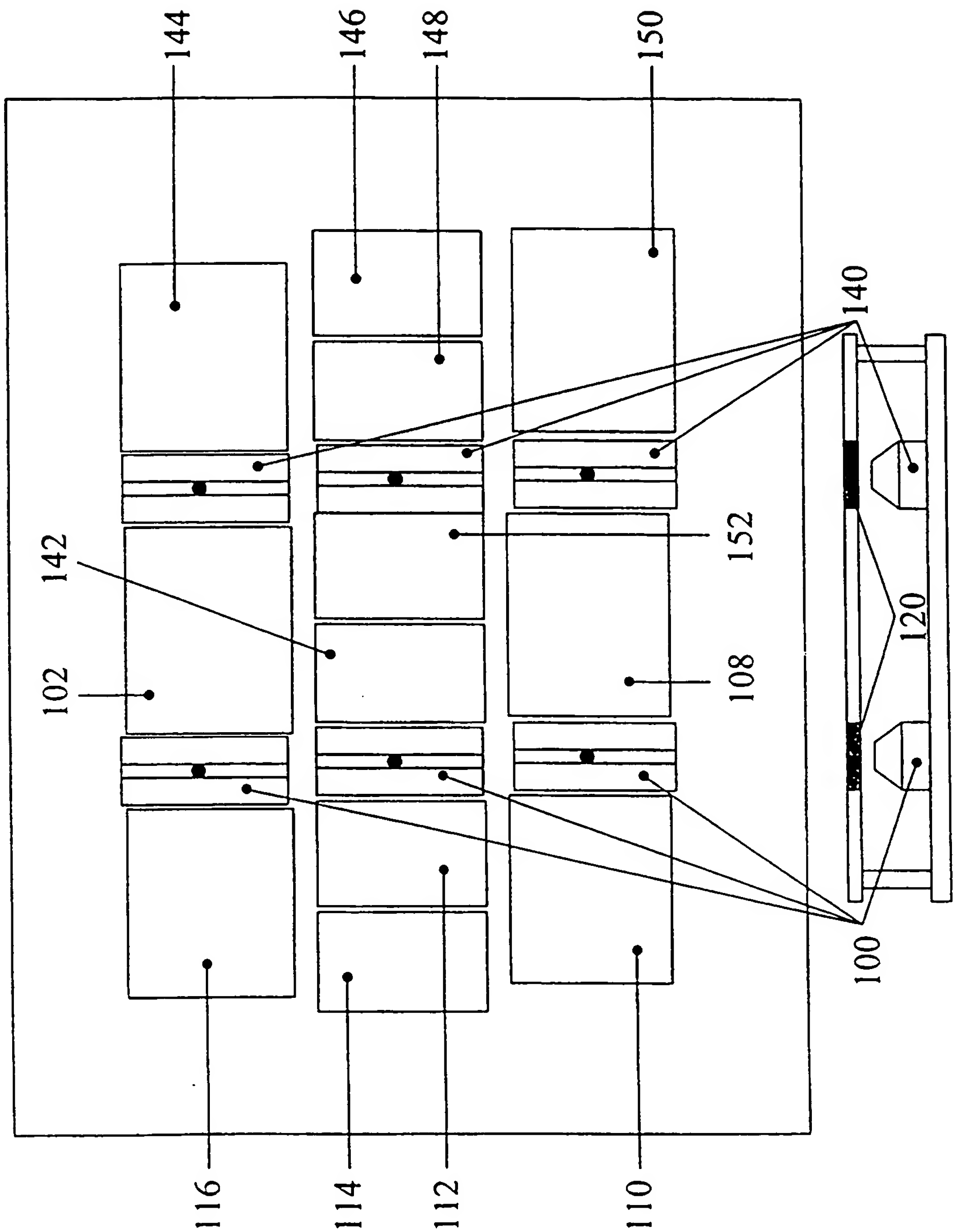

Figure 7A

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/27648

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : G11B 7/00
US CL :369/44.11, 44.41, 112.01, 112.29, 121
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 369/44.11, 44.12, 44.41, 112.01, 112.29, 120, 121, 122

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WEST
search terms: monolithic NEAR20 (head or pickup), vcselS, mirrorS NEAR20 stepS, plurality NEAR20 vcselS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A,P	US 6,084,848 A (GOTO) 04 July 2000, entire document.	1-42
A,P	US 6,023,450 A (PARK et al) 08 February 2000, entire document.	1-42
X -- A	US 5,808,986 A (JEWELL et al) 15 September 1998, entire document.	9, 14 ---------- 1-8, 10-13, 15-42

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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"&" document member of the same patent family

Date of the actual completion of the international search 17 JANUARY 2001	Date of mailing of the international search report 01 MAR 2001
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